Investigation of Contamination Effects on Laser Induced Optical Damage in Space Flight Lasers

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Outline

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- Common Damaging Contaminants
- Conditional Effects
- Non-linear Optical Behavior
- Quantization
- Trapped Energy
- A Digression
- Conclusions

Introduction

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- Why laser based satellites.
  - Active vs. Passive measurements
  - Time and Spatial resolution

Challenges

- Spaceflight laser challenges
  - Size
  - Weight
  - Power
  - Reliability
  - Environment

Power Limitations

- Power in space is limited
  - Power in, solar cell
  - Power out, radiators
  - Power transport

Reliability

- Spaceflight
- High Power Density
- High Shot Count
- No Maintenance
- High Cost
- Environment
- Higher Risk

- Land based
- Lower Average Power Density
- Maintenance
- Lower Cost per output
- Environment
- Lower Risk

Environment

- Vacuum
- Radiation
- Microgravity
- Thermal
- Contamination

Contamination

- Contamination is:
  - Something present that is unwanted
  - Dynamic
  - Multicomponent
  - Environmentally dependent behaviorally
  - Time Dependent

Spaceflight Laser Contamination Environment

- Internal Environment
  - Air Pressurized
  - Nitrogen Purged, Pressurized
  - Vacuum

Common Contaminants

- Particulates
  - Metal, Oxides, Organic fibers, Skin flakes, polymer particles
- Molecular
  - Plasticizers, Oil, Skin Oils, Polymer outgassing, Solvent vapor, Cleaning product residue, Decomposition products, Soldering rosin

Conditional Effects

Molecular Contaminants behave differently in different environments.

Primary Behaviors:

- Oxidation
- Photolysis/Volatilization
- Refractory Material Formation

Surface Effects

- Surface behavior is highly dependent upon its environment
- Surface energy is larger than the tensile strength of the base material
- Surface energy is decreased by the adsorption of materials
- Surface energy is seldom uniform on a surface
- Surface energy is molecular scale 10^{-9} meters

Surface Properties

- Terrestrial Surfaces are covered with water
- Water on the surface is not like bulk water
- Surface fields are on the order of 10^{10} V/M
- Surface fields change the behavior and properties of materials by inducing polarization and affecting symmetry
- Pristine surfaces have higher surface energies
- High curvatures result in high surface energy

Non-linear Optical Behavior

Non-linear optical behavior is due to the interaction of radiation with induced and permanent multipoles

- Interactions are field induced
- Interactions are solely due to multipoles
- Fields in materials are due to compositional, thermal, mechanical and electric gradients
- Asymmetry induces anharmonicity which results in non-linear optical behavior

Induced Non-linearity

Non-linearity is amplified or induced by:

- Surfaces
- Stresses
- Compositional Gradients
- Point Defects
- Thermal Gradients
- Excitational Gradients
- External Fields

Applied Field Effects

Fields applied to asymmetric materials increase the interaction of the material with the applied field

- Distortion of the local electric field is increased by the applied field
- Electromagnetic field interaction increases with asymmetry
- Asymmetry increases with electromagnetic field interaction
- Asymmetry fields propagate about the original asymmetry

Surfaces and Fields

- Surfaces have large fields
- Surface adsorption is due primarily to multipole interactions
- Optical Non-linearity is entirely due to multipole interactions
- Applied radiation amplifies local fields
- Applied radiation on surface adsorbed materials greatly amplifies non-linear optical behavior (factors of millions or more.)

Quantum Behavior

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- “Normal” quantum mechanics describes low energy flux systems
- Strict quantization rules apply to stable long duration non-interacting states
- Condensed, particularly solid states, violate quantization assumptions
- Absorption and Emission probabilities assume steady state and low photon arrival rates.
- Material properties are assumed to be constant

Trapped Energy

- High intensity lasers produce high fields
- High fields affect materials properties
- Short laser pulse durations are on the order of material transition times
- Intense laser fields modify the properties of materials
- If absorption probability is increased due to the applied field, and photon flux is sufficiently high, energy can be trapped in a material

Excitons

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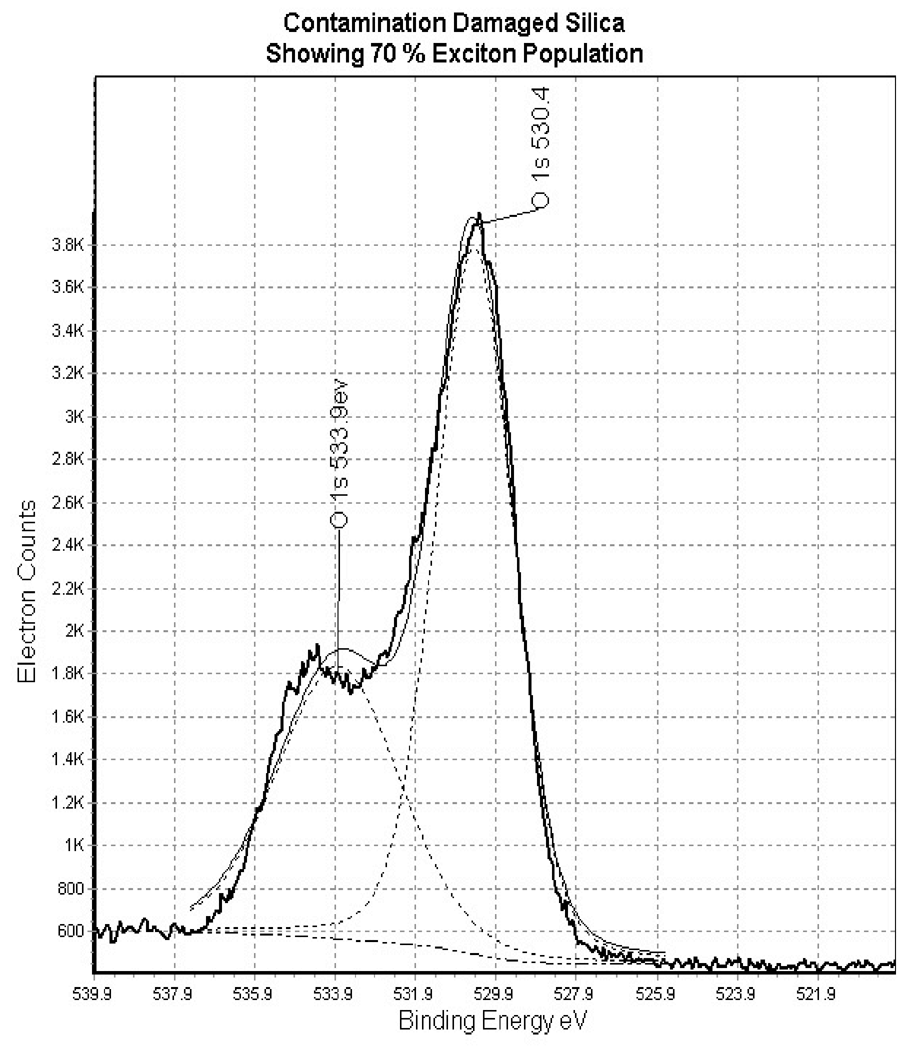
- Energy trapped in matter creates excitons
- Excitons vary in stability based upon emission probability and reactivity
- Solid state materials tend to form stable excitons
- Glasses form excitons from:
  - Radiation (alpha, beta, neutron, gamma, x-ray, ultra-violet)
  - Rapid cooling (thermal stresses)
  - Laser Radiation
- Can be made to photo-emit
- Create large internal fields

Laser Induced Excitons

- ESCA analysis shows the internal energy in silica
- Oxygen 1s shows a decrease in ionization energy
- Peak area is representative of population distribution
- This exciton population is 3000 times the previously projected maximum value
- The energy stored is about one third the heat of formation of silica
- Emission energy can be induced
- Surface adsorption energy of advantitous hydrocarbons increased to 2 eV



Silica Exciton Significance

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What is the significance of large silica exciton concentrations in lasers?

- Large exciton concentrations mean large surface energies
- Large adsorption and materials effects
- Large non-linear effects
- Potential catastrophic release of energy
- Potential identification of the weakening of once damaged laser optics
- Potential lead in the mechanism(s) of contamination related laser optical damage

Silica Exciton Significance

Where else might high concentrations of silicaceous excitons be of significance?

- Silicaceous materials make up most of the solid matter in the universe
- Silicaceous excitons can be stimulated to emit
- Storage of large amounts of energy in silicaceous material could resolve a number of interesting issues
- The significance has probably not been considered due to the presumed low concentration

Interstellar dust

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- Excitons are stored energy
- Formation of silicaceous material in stellar events will result in rapid quenching from high temperatures
- Rapid quenching stores energy in stress (excitons)
- Inter stellar dust has a broad emission that has been unexplainable
- Excitons will emit radiation in a broad spectrum from the UV to the near infrared
- In the presence of cosmic radiation, emission can be stimulated

Larger Particles

- Excited material has higher surface energy
- High surface energies attract strongly
- Large particle agglomerates will heat with amplified spontaneous emission
- Stimulated emission will result in more energy release

Earth, or a really big particle

- Solar irradiance is constant +/- 0.1%
- Solar flare activity has been linked to global temperature swings (Little Ice Age-1645-1715)
- Permafrost was seen in more temperate climates
- Solar flares result in increased radiation, primarily at the magnetic poles
- Snowshoe Hare and Arctic Fox, populations, among others, cycle with solar flare activity and resultant arctic tundra temperature
- The cooling of the planet, is slower than predicted by current thermal balance models

Hypothesis

- Exciton emission from silicaceous material can be induced with radiation
- The earth's magnetic field redirects the radiation impact to the poles
- Radiation impinging at the poles would release energy from silicaceous excitons
- This energy release would decay to thermal energy
- Heating of the core would result in convection of the core
- Silicaceous excitons can carry ionizing energies
- Circulating Ions create currents and magnetic fields

Conclusions

- Laser materials interactions are not well understood
- Spaceflight lasers offer significant challenges
- Understanding non-linear optical behavior is key in understanding high intensity laser induced optical damage
- Contamination is inevitable
- Understanding the mechanisms of laser optical damage is crucial in managing the risks
- High concentrations of excitons have been measured in laser optical damage
- There are wide implications of the measured exciton levels

Acknowledgments

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